Modelling Migration in the Sahel: An alternative to cost-benefit analysis

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1 The issues

Environmental issues pose enormous risks for all populations, but especially for the vulnerable. There have been many attempts to measure the risks and the costs of environmental episodes. Such measurement is seen in many quarters as a matter of increasing urgency as a result of the prospect of climate change. The economic approach to vulnerability measurement is based on cost-benefit analysis (CBA). CBA itself is predicated on the proposition that all relevant impacts of climate change can be given a numerical value. A clear argument for this approach was offered by the late David Pearce [13]. The value to be chosen is what the “market” value of the marginal costs and benefits. Where there is no relevant market, individuals must be able to state what they would pay to be able to stay where they are or the money they would accept as an inducement to move from where they are. In many, perhaps most, cases valuation is by no means so simple since actions are taken in response to environmental and political events. In this paper, we investigate one such case concerning the Sahel region at the edge of the Sahara.

In the Sahel[1], typically individuals migrate but who migrates and whither they migrate is a household decision. It would be remarkable if such decisions taken by one household were not influenced by the behaviour of other households. Consequently, any attempt to value migration will depend not only on environmental and political events of the moment but also on the social norms that emerge as household decisions are reached and as those decisions are discussed among members (or heads) of households in the same communities. This sort of social decision making does not fit easily with the sort of economic theory with its monetization arguments on which CBA is based.[8]

Due to the way a standard economical approach measures and evaluates cost and benefit, lots of social context in the examined domain gets lost. This social context, in its turn, might have a significant influence on the outcomes of the CBA results and thus be never evaluated. The core question addressed in this paper is whether and how agent-based social simulation can provide a superior alternative to conventional economic analysis. In particular, do models constrained by evidence rather than simplistic theory provide a better guide to policy? The model reported here demonstrates that the answer to this question is in the affirmative.

2 The evidence[2]

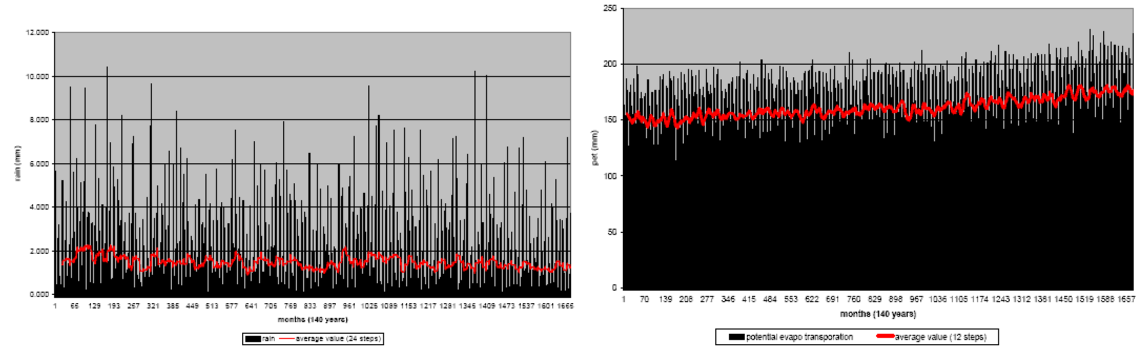
The Sahel is subject to the greatest climatic variation of any region in the world[3]. One feature of this variability is the unpredictable occurrence and duration of droughts. Several studies [1, 14] have assessed the impact of intermittent droughts and their resulting catastrophic effects.

These circumstances of the case offer a good testbed for validating the theories postulated by this paper about agent-based modelling being a better alternative to CBA than a conventional economic approach. CBA will be

[1]The southern edge of the Sahara desert covering parts of Mali, Nigeria, Senegal, Chad, *etc.*

[2]The descriptive verbal evidence used in the design of the model reported here came entirely from Stockholm Environment Institute Oxford office, [14, 5, 1] .

[3]The reasons are not fully understood but see [10, 9, 19, 18] who offer alternative hypotheses.



(a) PREC: monthly rainfall with smoothed trend line (smoothed by 24 steps)

(b) PET: Potential monthly evapotranspiration with smoothed trend line (smoothed by 24 steps)

Figure 1: meteorological data provided by SEI

examined with respect to cost as a loss of well-being and a benefit as any gain in well-being. These loses and gains will be represented through willingness to pay to avoid a loss or willingness to pay to secure a gain.

The model reported here draws on continuous monthly climate data (specifically precipitation and evapotranspiration) for 140 years. The climate data is supplemented by qualitative descriptions of farming and migration provided by domain experts from the Stockholm Environment Institute (SEI) Oxford office.[4]

The meteorological data, depicted in figure 1, shows if anything, a slight drying trend in rainfall, but with significant variability, and rapid increase in PET (usually due in part to rising temperature).

The typical household size, in the region, ranges from 6 to 8 members. The decision whether to cultivate or not, is made by the rules, extracted out of the cropping model of Bharwani et al. [14], on the basis of monthly weather forecast and portfolio of the household. These rules (see figure 2) concerning crop strategies were extracted and translated into declarative rules for the Sahel model .

In times of severe drought, households send their better educated to urban areas and their less well educated but more able and fit members to other rural areas as hired labour or peasant farmers. A decision whether to move to other rural or urban areas also depends on the presence of social links via friend or family in the city. In the absence of these social links and education, individuals are sent to other rural areas - generally southward where there is greater rainfall.

In extrenme cases, whole households migrate southwards and continue in agriculture on marginal land but with larger plots. Migration is the last option and for individuals is not permanent. Individuals move to the cities in the dry seasons during periods of drought when there is no work to be done in agriculture and then return after the drought. The scale of migration is evidently dominated by rainfall.

Drought is not the only cause of vulnerability in Sahel. It acts in conjunction with other stressors such as declining soil fertility, market fluctuations, prevalent poverty and the impact of HIV/AIDS [5]. Apart from the last of these, drought is the stress trigger. For this reason, climate variability was the factor that drove the modelling of stressors in the Sahel model.

3 Model design

In order to emphasise social response to climatic changes and represent adaptive behaviour of the agents a whole set of rules was developed upon which an farmer-agent will draw its decisions and react to changes in environment he lives. Furthermore agents were provided with social links in order to let them influence each other in their dicsisions.

The model defines HOUSEHOLDS as basic units. Household is represented as a goal-oriented entity with modelled cognition that links goals and behaviour. Decisions are implemented only at the household level. Individual decision of migration is followed by request of the individual who wants to migrate to the household about availability of the opportunity to migrate. Household is several agents living together, where all income and available resources are pulled together and shared equally. Model anticipates two types of households - poor farmer-agents and better-off farmer agents. This distinction follows from evidence [14]. As the simulation starts, households are

[4] Tony Nyong, Sukaina Bharwani and Ruth Butterfield.

Table 2. Rules for household decision-making.
(BN, below-normal forecast; N, normal forecast; AN, above-normal forecast. Left column is amount of cash available in Rand. M, maize; B, Butternut; C, cabbage.)

	BN forecast			N forecast			AN forecast			no forecast		
	M%	B%	C%	M%	B%	C%	M%	B%	C%	M%	B%	C%
poor farmer												
September												
cash < R435	25	—	—	25	—	—	25	—	—	25	—	—
R435 < cash < R525	100	—	—	100	—	—	100	—	—	100	—	—
R525 < cash < R570	50	50	—	50	50	—	50	50	—	50	50	—
cash > R570	25	75	—	—	—	—	—	—	—	—	—	—
October												
cash < R435	100	—	—	—	—	—	—	—	—	—	—	—
January												
cash < R435	25	—	—									
R435 < cash < R450	100	—	—	100	—	—	100	—	—	100	—	—
R450 < cash < R495	75	—	25	—	—	—	—	—	—	—	—	—
February												
cash > R495	—	—	100	—	—	—	—	—	—	—	—	—
better-off farmer												
September												
cash > R750	—	100	—	—	100	—	—	100	—	—	100	—
January												
cash > R630	—	—	100									

Figure 2: cropping rules from [14]

created with a dynamic amount of members in them and random relationships between households are allocated. The number of relationships is randomly bounded by the upper limit which is a parameter.

The social links (RELATIONSHIPS) assigned to the households represent the safety nets for the poor households. In dry times it is useful to have social links as the probability of sending one or more household members to the related household increases. These members can be claimed back with time once the household they were born in recovers from its misery.

Social response of the household to the stressors of the world is the core part of the Sahel model since this will give direct hints on the willingness of the household to accept certain circumstances or not. If households' income is negatively affected in the long term, there are several community-based risk coping strategies implemented involving particular kinds of migration among other things:

- Suffering households might decide to change their livelihood which includes customization of the cropping strategies. This might possibly lead to further negative effects in case of strategy mismatch.
- Suffering households might consider that partial migration might be the way out of the misery. This approach assumes three types of migration - remittance migration, loyalty migration or urban migration. Both remittance and loyalty migration are either temporary or permanent, rural migration is permanent.
  - In case of remittance migration some household members (mostly members in their age of work) go out to work and earn money, part of which is remitted to their original household. Remittance migration can only happen to the related households (i.e. household of relatives of household with friendship links).
  - In case of loyalty migration, old people who are not capable of work anymore are accepted by the related household if it has free capacities. The extra person accommodated can result in the household becoming poorer as resources are limited. The effect can be to trigger a further migration of the additional person as the household cannot sustain the extra burden.
  - It is assumed that rural migration is suitable only for young household members. Once an agent decides to move to the city it vanishes from the simulation.
- Migration involving the entire household is a last resort for the suffering household. It involves resettlement to a new location. This migration leads to further degradation and social conflicts according to SEI.

The cropping model from Bharwani et. al. [14] was used to determine modelled crop yields, weather forecasts and market effects.

FEEDING household members is a procedure that differs for both types of households. Cash-farmers never plant maize and therefore always buy their food from the market. Poor farmers try first to consume maize from their own production that has been stored and if this is not sufficient they are forced to buy complementary food from the market. In case a household has lack of food and is short of cash all the available food reserves are pooled together and distributed between household members with the following priority: children become the highest priority, followed by members with highest labour value and closing with the rest of members with low priority.

ENVIRONMENT households live in has cellular landscape representation with distance-dependant spatial interactions. Household is capable of autonomous actions in response to changes in its environment (cropping strategies and migration decisions). Each household manages a single parcel at a fixed location. The land parcel serves as a home garden and can contain up to 30 lines of planted crop [1].

See appendix for further modules implemented in the Sahel model.

4 Implementation issues

In order to address issues discussed in the previous chapter, it is natural, convenient and effective for purposes of validation[16] to model agents' behaviour declaratively.

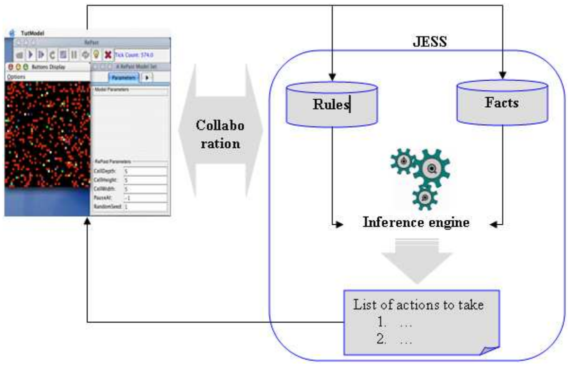


Figure 3: JESS-RePast collaboration

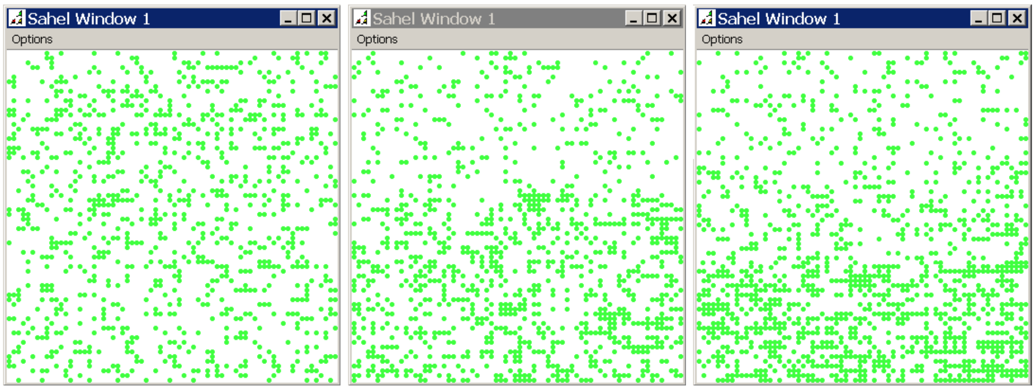
Most programming is procedural: the programmer tells the computer what to do, how to do it and in what order. Procedural programming is well suited to problems in which the inputs are well specified and for which a known set of steps can be carried out to solve the problem. It is clearly useful and enormously successful in physical science applications. At the same time, procedural programming supports only a poor representation of human cognition because, as we gain experience and are influenced by others, we reason about our decision making procedures and might, as a result, change the steps and/or the order of the steps we take in reaching decisions. Moreover, the order in which we consider issues and the conclusions we draw are contingent on both environmental stimuli and our own internal states. It is far easier to represent this view of cognition as a logiclike process in which statements on a database activate rules that add further clauses to the database. The order in which rules fire can be consistent with a formal logic or by some arbitrary conflict resolution scheme.[12] Perhaps the biggest advantage of declarative implementations is the ability of agents to use knowledge in ways that the model designer did not foresee.

One virtue of the Sahel model is that it shows with a high level of confidence that the modeling approach meets the standard acceptance criteria: function, performance, usability, features, and capabilities[5].

For reasons long rehearsed elsewhere (e.g. [11]), cognition is best represented declaratively by logic-like rules. At the same time, physical processes most naturally represented procedurally. These two modelling paradigms were achieved by incorporating Jess[2], the Java Expert System Shell, into a Java programming controlled by RePast[3]. This implementation design is depicted in figure 3. RePast serves as a central place for simulation control and time-scaling. The ripening of the crops and other environmental effects are modelled procedurally in RePast due to the assumption that they do not require reasoning abilities. Jess is used for representation of human reasoning solely. Facts and rules a person need to know for reasoning (cropping decisions, migration, distribution of food etc.) are put in Jess by RePast. Upon these data inference engine produces an agenda which causes particular rules to fire.

This architecture uses both declarative and procedural knowledge at different times, taking advantage of their different strengths.

[5] In part, the declarative approach described here arises out of the history of development and application of the SDML language at the Centre for Policy Modelling [6]. In the course of further development on declarative modeling two approaches were developed - database approach [15] and Jess-Repast approach.



(a) initial pattern of household distribution

(b) Pattern after 1000 steps

(c) final migration pattern after 1680 steps

Figure 4: Migration pattern

5 Preliminary results

The first results based on this modelling approach are presented here. The virtues of this model over CBA are becoming evident. The outputs from the model include not only the patterns of migration for comparison with empirical evidence (see figure 4), but also give verbal accounts of the reasons for particular migratory decisions affecting individuals and households (see excerpt from simulation transcript in appendix). These outputs are then available for the development or application of measures of vulnerability and stress. Moreover, the value of these measures can be assessed by validating the models against further expert data and also by interview and similar evidence directly from affected stakeholders. If thought useful, it will also be possible to perform cost-benefit analysis on the outputs from the model in order to assess independently the value of that approach.

The declarative approach also supplied a good tool in terms of stakeholder interactions. The implementation of the farmers' knowledge in the Sahel model was efficiently translated into rules. The evidence used is best described qualitatively and the rules individuals give for their behaviour are of qualitative nature as well. Therefore as argued by Moss and Edmonds in [17] validation of software agents as adequate representations of real actors is made smoother by designing agents to perceive events specified by qualitative descriptions, maintain the qualitative terms during processing these qualitative perceptions and then act in way that can be characterized qualitatively. A proposed way of maintaining the qualitative link between the language of the actors and the language of the agents is to use systems where perception conditions and actions followed on these conditions can be defined in rules. These rules can be then used by some inference engine with actions specified by consequences of these rules. One of such rule based inference systems is an expert system allowing infer on a given set of rules. Furthermore, the extraction and arrangement of the farmers' reasoning in the rule form simplified discussions about the model with people not familiar with it. Information gathering and presentation of the rule-based / expert systems is a well studied topic. Rule-like presentation of the cognitive aspects of the model increases comprehensibility and acceptance of the model by non-scientists.

6 Conclusion and Further Research

Land-use systems contain important sources of complexity such as heterogeneity and interdependencies which are difficult to explore with usual statistical apparatus. Sahel model with its ABM approach provides a test bed in better understanding "emergent" properties in decision-making modelling and provides an appropriate framework for further vulnerability issues investigations. According to the vulnerability protocol of NewWater workshop[6] any formal framework for assessing vulnerability must specify (1) the exposure units which are being considered (households and individual household members), (2) the set of stresses that represent any associated risks (i.e. drought, social conflicts), and (3) the abilities of exposure units to cope, recover, or adapt (social response of the households to the environment). These requirements are met by the discussed model. It is a widely discussed issue that outcomes of ABM models, especially if they are individual based, reproducible only by closely reproducing its software implementation. With a declarative approach for the Sahel model it was attempted to escape the problem

[6] "Modelling Vulnerability In Montpellier", 3-7 April 2006, hosted by University of Montpellier, organised by Nils Ferrand (CEMAGREF) and Tom Downing (SEI Risk, Livelihood and Vulnerability Programme).

of close dependence of the result of an ABM on its implementation basis by making at least the simulation flow independent from implementation. One can still argue that using another inference engine will not produce the same data but this discussion is going beyond the scope of this paper.

In the ABM it is important to choose the right tool for the right job. This paper presents a promising alternative to the usual modelling approaches. The declarative approach used in this paper was also designed to provide a lightweight alternative to SDML [4].

A widely held belief about cost benefit analysis is that everything can be reduced to numbers [13]. This is somewhat odd if one observes a migration phenomenon - there are no numbers. The evidence we obtain is best described qualitatively and the rules individuals give for their behaviour are of qualitative nature as well. In such a cul-de-sac situation an ABM can be often the way out. The model provides a story which can be validated against a variety of statistical evidence. The model itself does not make cost-benefit analysis but it forms a different policy of discussion and can provide a good test bed in better understanding of the driving factors important for the intended analysis.

A frequent problem with CBA is that it requires the cost or benefits being tangible, hard and financial, while typically the cost or benefits are hard and tangible, but also soft and intangible. Caution should be taken here against claims like "if you can't measure it does not exist / it has no value". Especially in social context, frequently the intangible benefits and cost are clearly predominant. In order to increase the tangibility it is necessary to understand why the biggest part of population or a single agent is doing something - this is the most desirable bit of information. Only if we are able to understand why people take this or that decision under certain circumstances will we be able grasp the affect of uncertainty on their actions. This in turn might mitigate the most common object to the CBA frameworks' use of a monetary metric to place the pros and cons of an action on a common footing [7]. Furthermore, the model provides an assessment of the realism of scenarios in comparison with existing real-world data.

In the future the Sahel model will be advanced in collaboration with scientists focusing on investigation of vulnerability and in continuation from a recent workshop[7] where an earlier version of this model was presented. The objective is to use our declarative modelling framework to identify “qualitative” indicators of vulnerability, in the form of sets of rules in the model and their sequences of activation. We hypothesise that migration of single agents is one possible indicator because it signals that food stocks are becoming low or the livelihood of the household is going down. But it is possible to argue that migration of the whole household might be a better indicator. In the future work it is intended to experiment with the model to compare how these two indicators influence each other and correlate with number of death of individuals and of related households. These factors are not easily captured with concise numerical indicators that are typically used to investigate vulnerability.

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[7] see previous foot note

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APPENDIX

Modules used in Sahel model

MARKET: Market module was designed with two different dynamics for poor and better-off households thereby to incorporate infrastructure differences between the two farmer groups. Any overall decline in yield leads to an increase in grain price as a result of competition for the limited quantity of products in the market.

CROP: This module represents cropping decisions with respect to a land parcel which is in the possession of the household concerning three crops and based on the FAO Water Requirement Satisfaction Index (WRSI) algorithms. A parcel can contain up to 30 rows of planted crop. The modelling of the crop-water balance is based on the WRSI. Potential yields are calculated on the basis of with PET and PREC as input and a crop-water balance algorithm based on the WRSI algorithm as calibrated using the yield data obtained during fieldwork by SEI.

WEATHER AND WEATHER FORECAST: These modules calculate weather forecast issued to the farmers. The weather module is necessary for the correct work of the market module as the latter calibrates its prices according to climatic changes.

Excerpt from simulation transcript for one random household

HH - household, PF - poor farmer, BF - better-of farmer, HM - household member, HHS - household storage, HHF - amount of household's fileds overall, HHM - amount of household's maize fields, HHB - amount of household's butternut fields, HHC -amount of household's cabbage fields

```
HH-75 created at cell (45/97); portfolio type - PF; 5 people
HM-1:  (HUNGER no) (HEALTH good) (AGE 12) (LABOUR 100%)
HM-2:  (HUNGER no) (HEALTH good) (AGE 20) (LABOUR 100%)
HM-3:  (HUNGER no) (HEALTH good) (AGE 33) (LABOUR 90%)
HM-4:  (HUNGER no) (HEALTH good) (AGE 6) (LABOUR --)
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HM-5:  (HUNGER no) (HEALTH good) (AGE 18) (LABOUR 100%)
HHS-75 created & initialized, HHF = 0, HHM = 0, HHB = 0, HHC = 0
...
<September>
(!)  HH-75:  not enough food for all HM; => it's cropping month and feeding priority is (1)HM with highest labour, (2)young HM, (3) rest HM
HM-1:  (HUNGER yes) (HEALTH normal) (AGE 14) (LABOUR 90%)
HM-2:  (HUNGER no) (HEALTH good) (AGE 22) (LABOUR 100%)
HM-3:  (HUNGER yes) (HEALTH normal) (AGE 35) (LABOUR 80%)
HM-4:  (HUNGER yes) (HEALTH normal) (AGE 8) (LABOUR 90%)
HM-5:  (HUNGER no) (HEALTH good) (AGE 20) (LABOUR 100%)
HH-75:  planted 12 lines of maize
...
<November>
(!)  HH-75 not enough food for all HM => it's cropping month and feeding priority is (1)HM with highest labour, (2)young HM, (3) rest HM
HM-1:  (HUNGER yes) (HEALTH week) (AGE 14) (LABOUR 70%)
HM-2:  (HUNGER yes) (HEALTH normal) (AGE 22) (LABOUR 80%)
HM-3:  (HUNGER yes) (HEALTH week) (AGE 35) (LABOUR 60%)
HM-4:  (HUNGER yes) (HEALTH week) (AGE 8) (LABOUR 70%)
HM-5:  (HUNGER yes) (HEALTH normal) (AGE 20) (LABOUR 80%)
HH-75:  yield (= 60.00) stored in HHS
<December>
HM-1:  (HUNGER no) (HEALTH normal) (AGE 14) (LABOUR 80%)
HM-2:  (HUNGER no) (HEALTH good) (AGE 22) (LABOUR 90%)
HM-3:  (HUNGER no) (HEALTH normal) (AGE 35) (LABOUR 70%)
HM-4:  (HUNGER no) (HEALTH normal) (AGE 8) (LABOUR 80%)
HM-5:  (HUNGER no) (HEALTH good) (AGE 20) (LABOUR 90%)
...
<August>
(!)  HH-75 not enough food for all HM => feeding priority is (2)HM with highest labour, (1)young HM, (3) rest HM
HM-1:  (HUNGER yes) (HEALTH critical) (AGE 19) (LABOUR 70%)
HM-2:  (HUNGER yes) (HEALTH bad) (AGE 27) (LABOUR 80%)
HM-4:  (HUNGER yes) (HEALTH week) (AGE 13) (LABOUR 70%)
HM-5:  (HUNGER yes) (HEALTH bad) (AGE 25) (LABOUR 80%)
HM-6:  (HUNGER yes) (HEALTH normal) (AGE 3) (LABOUR --)
==> HM-6:  is about to be send to related HH-115
==> HM-13/19:  is thinking about migration to city
<October>
(!)  HH-75 not enough food for all HM => feeding priority is (2)HM with highest labour, (1)young HM, (3) rest HM
HM-2:  (HUNGER yes) (HEALTH bad) (AGE 27) (LABOUR 20%)
HM-5:  (HUNGER yes) (HEALTH bad) (AGE 25) (LABOUR 30%)
HM-6:  (HUNGER yes) (HEALTH normal) (AGE 3) (LABOUR --)
==> HM-6:  was sent to related HH-115
==> HM-1/4:  moved to city
<December>
(!)  HH-75 not enough food for all HM => feeding priority is (2)HM with highest labour, (1)young HM, (3) rest HM
HM-2:  (HUNGER yes) (HEALTH bad) (AGE 27) (LABOUR 10%)
HM-5:  (HUNGER yes) (HEALTH bad) (AGE 25) (LABOUR 10%)
HH-75:  yield (= 10.50) stored in HHS => too smal amount of yield (drought/not enough labour)
==> HH-75 moves to another parcel
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